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DEVELOPMENT OF A MICROCOMPUTER-BASED EXPERT SUPPORT SYSTEM: APPLICATION OF THE ANALYTICAL HIERARCHY PROCESS TO THE PRIORITIZATION OF RELIABILITY AND MAINTAINABILITY MODIFICATIONS

THESIS

Joseph B. B. Nettleton
Captain, USAF

AFIT/GLM/LSY/88S-54

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THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Logistics Management

Joseph B.B. Nettleton, B.A.A.S.
Captain, USAF

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Preface

This thesis would not have been possible without the support of HQ TAC/SMO-R&M, my friends, and my wonderful family.

The purpose of this study was to demonstrate the decision making capabilities of expert support systems in a microcomputer environment. The Tactical Air Force's managers involved with reliability and maintainability modifications will be able to use the author's ESS model to improve the credibility and documentation of their decisions.

I thank God for providing me with an understanding thesis advisor - Major Curt Cook, and my reader - Major Ken Jennings. Thanks are also in order for Major "Skip" Collins and the people of the Special Management Office for Reliability & Maintainability at HQ TAC - their insight into the prioritization process and willingness to support me is appreciated.

Last but certainly not least, I thank my wife Justine who encouraged me and my children who have been patient with me.

Joseph B.B. Nettleton

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Abstract

Expert support systems (ESS) are ~~systems~~ designed to help decision makers deal with complex, nonprogrammed decisions. This ~~research~~ thesis entailed development, implementation, and validation of an ESS in a "real-world" environment. The problem solving technique used here is the analytic hierarchy process, adapted to the microcomputer by ~~Dr.~~ Foreman and others from Decision Support Software in the form of the software package Expert Choice. Included in the research is a background study on decision making in general, the Analytical Hierarchy Process, the evolution of expert support systems, and ~~United States~~ U.S. Air Force reliability and maintainability ~~(R&M)~~ issues.

The complex decision chosen for this project was Headquarters Tactical Air Command's annual prioritization of R&M modifications. These ~~R&M~~ modifications, known as Class IV-B modifications, improve the effectiveness of fielded weapon systems. Due to a limited budget, not all modifications can be funded in a given year. Therefore, TAC must prioritize the modifications, trading off benefits offered with the cost of each proposed change. This research includes a model designed by the author using Expert Choice to prioritize these modifications that offer the greatest benefit/cost return. The model improves responsiveness to changes, increases flexibility, and improves the reliability of the decision-making process. (KR)

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I. Introduction

General Issue

> "Reliability and Maintainability have long been recognized as valid program considerations impacting both combat capability and logistics supportability (Tactical Air Command, 1987d:v)."

Modifications to deployed weapon systems are necessary to improve their reliability, maintainability, and effectiveness, thus enhancing their combat capability and logistic supportability. Dr. Benjamin S. Blanchard states in his book, Logistics Engineering and Management, these modifications "... are initiated to correct deficiencies and/or to improve the product (Blanchard, 1986:287)." For the Tactical Air Force (TAF), these changes modify the aircraft and weapon systems that are the front line defense of the United States. To keep these critical weapon systems fully effective and capable of ensuring our national security in light of the constantly changing global threat, modifications are vital.

Each year in the Program Objectives Memorandum (POM), Headquarters Air Force Logistics Command (HQ AFLC) submits its proposal for funding, including a prioritized list of modifications (mods) to correct deficiencies for fielded weapon systems. These are known as Class IV modifications and fall into two categories. The first category, Class IV-A modifications, are related to safety and will not be discussed in this research. The second, Class IV-B modifications, which increase the operational suitability of aircraft by "enhancing their reliability and maintainability (R&M)(Tactical Air Command, 1988b:III-5)" will be dealt with here. Specifically, the problems associated with deciding which of the Class IV-B modifications to fund each year from a limited (and shrinking) budget will be the focus of this research.

The Tactical Air Command (TAC) Special Management Office for Reliability and Maintainability (SMO-R&M) is tasked each year to prepare a prioritized list of all Class IV-B modifications for submission to HQ AFLC (Tactical Air Command, 1986a:18). "SMO-R&M spearheads HQ TAC's effort to enhance combat capability by increasing the reliability and maintainability of the weapon systems (Tactical Air Command, 1988b:I-3)." To do this, each member of the TAF, which includes TAC, the United States Air Forces in Europe (USAFE), Pacific Air Command (PACAF), Air National Guard (ANG), Air Force Reserve (AFR), and the Alaskan Air Command (AAC), submits a list of modifications to HQ TAC/SMO-R&M for

consideration. Each of these commands has its own interests and priorities for the modifications. The task for SMO-R&M is to fold these lists together, prioritize the resulting single list, and present it to the TAF Commanders at their fall commanders conference. Following the conference, TAC submits the commanders approved list to HQ AFLC for inclusion in the AFLC POM and Volume II of the R&M 2000 Plan. (The R&M 2000 Plan is revised annually "in order to track, project, and report R&M impact on the operational support goals as well as to update the goals when appropriate (Tactical Air Command, 1987d:I-1).")

At a time when budget limitations are a reality, prioritizing this list is extremely difficult. The primary criterion for establishing the priority of the modification proposals is the benefit each offers, but overall cost and Life Cycle Costs (LCC) must be considered (Collins, 1988b). Informally this is referred to as striving for the "most bang for the buck," and is a complex problem requiring a significant amount of time and effort each year.

Decision making for managers and leaders of the United States Air Force (USAF) is itself a complex subject. Many factors are weighed in the typical decision making process, including needs of the Air Force, cost considerations, top-level guidance, adherence to applicable regulations, and common sense. Clearly, prompt, accurate decisions must be made in today's Air Force in spite of the complexities.

Expert Support System (ESS) software, commercially available at relatively low cost, is designed to help facilitate managerial decision making. Techniques to structure problems and to aid in decision making are becoming more common and are being incorporated into the personal computer (PC) environment. Air Force managers could make use of these techniques and available low-cost software to improve their decision making. The objective of this research is to develop an ESS using such low-cost software for use by SMO-R&M in prioritizing the TAF Class IV-B modifications.

Problem Statement

The general problem addressed by this research is that managers:

> "are required to make complex decisions, based on competing criteria, and dozens of subcriteria, involving numerous alternative strategies, without the use of a comprehensive, easy-to-use, decision support tool. ...As a result, managers may make decisions without considering all the relevant, important criteria that influence the decision. In such cases, the risk exists that less-than-optimal decisions will be made... (Cook, 1986b:5)."

Specifically, the Air Force can not afford to make poor funding decisions. Changes or modifications to TAF aircraft for reliability and maintainability reasons are crucial to national defense. There is a finite amount of funding available to accomplish the myriad of modification proposals requiring funding. HQ TAC/SMO-R&M must determine the appropriate funding priorities to accomplish these critical modifications, considering the many cost/benefit tradeoffs of

the modifications, both individually and as a group. This is HQ TAC's method of influencing HQ AFLC on how modification money, designated for TAF aircraft, should be spent.

This research will entail development of a viable decision support tool in the form of an expert support system for use by the SMO-R&M managers, and document the application of the ESS to the specific problem stated above. The following section will describe TAC's Fiscal Year 1991 (FY '91) new start Class IV-B mod prioritization decision process. The SMO-R&M managers are projecting these new starts three years in advance for HQ AFLC's POM planning purposes. New starts, "...define new programs in terms of dollars and manpower to satisfy a valid requirement (Tactical Air Command, 1987c:II-2)."

The Class IV-B Mod Prioritization Process

Following production and deployment of a weapon system, a mission profile change or improved technology may make a Class IV-B modification to the system desirable or necessary. These modifications may be as simple as removal of a piece of sheetmetal from the belly of an F-15, or as complex as extending the life of the Air National Guard and Reserves' F100-PW-100 and -200 engines. SMO-R&M managers are faced with the complex reliability and maintainability decisions involving these critical weapon systems.

Class IV-B modifications can "nurse" along an aging weapon system or create an entirely new capability for these systems. Typically, a total of $90 to $100 million dollars

is annually allocated for these Class IV-B modifications. With all proposed FY '91 new start costs totalling nearly $1.42 billion dollars, less than ten percent of these modifications will be funded (Collins, 1988a). The question becomes one of prioritizing the "needs" to match available funding. Each system program manager (SPM) can make a valid case for the weapon system he or she is responsible for. Each weapon system has a vital role in the national defense. Should many small cost - small benefit mods be funded, or should a few more costly - larger benefit mods receive priority? The objective is to get the greatest benefit for each dollar spent.

The SMO-R&M managers are currently using time consuming manual methods, combined with costly mainframe computer resources, to prioritize their Class IV-B mods. A basic tenet of this research is that SMO-R&M can establish these priorities at a significant saving of both time and money using a PC-based expert support system developed by this author. (All acronyms and abbreviations used in this work can be found in Appendix D)

Research Objectives

During the course of this research the following steps will be accomplished:

1. Development of a comprehensive literature review of military and civilian sources on:

    A. Decision Making.

    B. Analytical Hierarchy Process.

C. Evolution of Expert Support Systems.

D. Reliability and Maintainability issues.

2. Research of applicable guidance and regulations for the HQ/TAC SMO-R&M.

3. Development of an expert support system model to help SMO-R&M prioritize the TAF Class IV-B modifications.

A. Demonstration of the model to both the decision makers and the experts.

B. Modification of the model as necessary.

C. Validation of the model with data from a previous year.

4. Documentation of the entire process.

II. Background and Source Review

Overview

This chapter will begin with a general review of all the diverse subjects researched. Then a more thorough review will follow of a portion of the applicable literature available on decision making, the analytic hierarchy process approach, the evolution of expert support systems, and United States Air Force reliability and maintainability (R&M) issues. Each of these topics will be discussed as they pertain to this research.

General Review

The subject nature of this research has brought about this review of seemingly unrelated subjects. The development of a micro-computer based expert support system to be used by the Air Force decision makers for R&M issues draws from diverse sources.

One of the areas studied is decision making as it pertains to complex decisions. The prioritization decision involves multiple criteria, such as benefits, costs, reliability, and maintainability issues, as well as a multitude of subcriteria on which the decision is based.

Another topic discussed is the analytic hierarchy process (AHP) approach to problem solving. Developed by Dr. Thomas L. Saaty, AHP structures complex decisions for decision makers (Saaty, 1980b).

A third area discussed, the evolution of expert support systems, describes how computer software has evolved and how ESS are useful to decision makers. The more advanced software systems can exercise computer power to formulate and solve complex problems. The expert support system used in this research - - Expert Choice - - was designed by Dr. Ernest H. Forman and is based on the analytic hierarchy process (Foreman and others, 1986).

Finally, the Tactical Air Force reliability and maintainability modification prioritization process is the specific complex problem addressed by this research. These diverse subjects tie together to make for an interesting research project that has real world applications.

Decision Making

This research addresses two primary topics in decision making. The first area described is how one differentiates nonprogrammed and programmed decision situations. The second area is complex decisions and how they are formulated to reduce complexity.

According to Nobel Prize recipient Herbert A. Simon (Fick and Sprague, 1980:49) decisions are either programmed or nonprogrammed (see Table 1). Programmed decisions are those that are "...repetitive and routine, to the extent that a definite procedure has been worked out for handling them (Simon, 1965:58)." Nonprogrammed decisions on the other hand are:

"...novel, unstructured, and consequential. There is no

cut-and-dried method for handling the problem because it hasn't arisen before, or because its precise nature and structure are elusive or complex, or because it is so important that it deserves a custom-tailored treatment (Simon, 1965:59)."

This research will focus on nonprogrammed decisions. The fundamental task of prioritizing a different list of weapon system modifications is clearly neither repetitive nor routine.

Table 1. Decision Making
(Adapted from Simon 1965:62)

TYPES OF DECISION

Programmed: Routine, repetitive decisions. Organization develops specific processes for handling them.

Traditional Techniques	Modern Techniques
1. Habit 2. Clerical routine: Standard operating procedures 3. Organization structure: Common expectations a system of subgoals Well defined informational channels	1. Operational Research Mathematical analysis Models 2. Electronic data processing

Nonprogrammed: One-shot, ill-structured novel, policy decisions Handled by general problem-solving techniques

Traditional Techniques	Modern Techniques
1. Judgement, intuition, and creativity 2. Rules of thumb 3. Selection and training of executives	Heuristic problem-solving technique applied to: (a) training human decision makers (b) constructing heuristic computer programs

"There is now good reason to believe that the process of nonprogrammed decision making will soon undergo as fundamental a revolution as the one which is currently transforming programmed decision making in business organizations (Simon, 1965:76)."

This "revolution" is now upon us. The personal computer, with its enhanced memory capabilities, is now the vehicle to apply these "new" techniques for decision making. Heuristic, according to <u>Webster's New Collegiate Dictionary</u> is,

"...providing aid or direction in the solution of a problem but otherwise unjustified or incapable of justification. Specifically of or relating to exploratory problem-solving techniques that utilize self-educating techniques (as evaluation of feedback) to improve performance < a heuristic computer program >."

The improvement of performance is the crux of this decision making problem. Improved decision processes will naturally improve the way the AF does business.

Decision making for leaders and managers of the United States Air Force is a complex subject. Many factors are considered in the typical decision process, including needs of the Air Force, cost considerations, top-level guidance, adherence to applicable regulations, and common sense. Timely, rational decisions must be made in today's Air Force in spite of the complexities.

As Simon also points out, the decision making process for executives has three phases:

"The first phase of the decision-making process - searching the environment for conditions calling for decision - I shall call intelligence activity (borrowing the military meaning of intelligence). The second phase - inventing, developing, and analyzing possible courses of action - I shall call design activity. The third phase - selecting a particular course of action from those available - I shall call choice activity (Simon, 1965:54)."

Each of these activities or phases is operative in this research. The first phase, intelligence gathering, is performed by HQ TAC/SMO-R&M "experts" for the TAF. Two separate HQ AFLC data bases, discussed later in this chapter, are needed to gather the data required to provide the TAF commanders, the decision makers, with the information necessary to make a decision.

The second phase, the design activity, is where the "experts" design the methodology to solve the problem. This is done through modeling of the environment in a manner consistent with what is actually found in the "real" environment. Criteria and subcriteria are selected that have a fundamental effect on the overall decision. For the 1990 new start modification prioritization, HQ TAC/SMO-R&M requested the Joint Studies Group (JSG) at HQ TAC to provide a methodology to solve the prioritization problem. The method the JSG proposed was Saaty's AHP. The topic of research by a former AFIT graduate student's (Darko) thesis was to validate AHP as a viable approach to this prioritization process (Darko, 1987). This current research builds on this foundation, developing a responsive ESS for use on a PC.

The third phase, the choice activity, selects the particular course of action from those available. Not only is the selection of the possible alternatives accomplished in this phase but identification of the "best" alternative is the goal. The modifications are the alternatives used in

this prioritization decision. The modifications are evaluated with the criteria using the priorities assigned when the model was formulated.

The process of the prioritization of these modifications is clearly not routine nor repetitive and cannot be classified, according to the Simon definition, as a programmed decision. Therefore the techniques described in Table 1 are not suitable for this application. Nonprogrammed decisions on the other hand are those that are handled by general problem-solving techniques. The heuristic problem solving technique applied in this research is the analytic hierarchy process. AHP, applied in the PC environment, allows responsive decisions that allow flexibility to facilitate changes, while improving the reliability of the decision process.

Often in the Air Force environment, application of the decision making process is delegated to a subordinate who may structure the problem, define the alternatives, and provide the ultimate decision maker with the recommended alternatives. The decision maker then provides the subordinate (the expert) with either approval of the recommendations or "further guidance." "An Expert," according to Webster's New Collegiate Dictionary is, "one who has acquired special skill or knowledge of a particular subject." In the Air Force, subordinates at the headquarters staff level positions are carefully chosen for their expertise.

Decision making, or any problem solving situation, begins with a clear definition of the problem or statement of the decision goal, as Simon states. "Problem solving is concerned with finding paths from initial states to desired states (Newell and Simon, 1972:828)." According to Dr. Curtis R. Cook, "To optimize the decision-making process, all relevant criteria and alternatives must be identified (Cook, 1987a:31)." These criteria and subcriteria, along with the alternatives, can be easily structured in a decision hierarchy.

Analytic Hierarchy Process

As stated above, this process of structuring complex problems was designed by Dr. Thomas L. Saaty and termed the Analytic Hierarchy Process (AHP). Saaty believed decision makers needed a process to reduce "formidably intricate systems to a sequence of pairwise comparisons of properly identified components (Saaty, 1980b:4)." Once defined in the hierarchy, a series of pairwise comparisons can be made between alternatives by decision makers at the lowest level of the hierarchy.

A hierarchy is defined as a "top-down structure of a complex problem that makes it easier to provide judgement and make choices (Foreman and others, 1986:G-5)." At the top of the process a goal to be attained is defined. Then all criteria that influence the decision are defined along with any relevant subcriteria. In this manner, the problem is structured, and the alternative courses of action are placed

at the lowest level of the decision hierarchy. Figure 1 presents a typical hierarchy. The criteria and subcriteria are determined by the decision maker. Each of the criteria is compared to "peer" criteria during pairwise comparisons to establish a rank ordering or priority of the criteria. Subcriteria are handled in the same way to give each node "weights" that sum to 1.0 for the entire hierarchy. At the lowest level of the hierarchy, each of the N (some number of) alternatives is compared, "one at a time against each other, with respect to their relative impact (Saaty, 1982a:240)," on each of the criteria and the subcriteria.

This process approach to complex problem solving was chosen for this research because in 1987, HQ TAC/SMO-R&M sponsored research from an AFIT operational research student, First Lieutenant Katherine Darko. The objective of her thesis was to validate AHP as a viable process for HQ TAC to use to prioritize Class IV-B modifications (Darko, 1987). Though not completely satisfied that AHP was the optimal approach for TAC to use in this application, her research was insightful.

Darko pointed out in her research that the TAF commanders did not have the opportunity to structure the decision tree. This is a time-consuming process. Structuring the problem, and performing all pairwise comparisons of criteria, subcriteria, and alternatives, is a long and tedious process when performed manually. The commanders' time is limited, and there are other

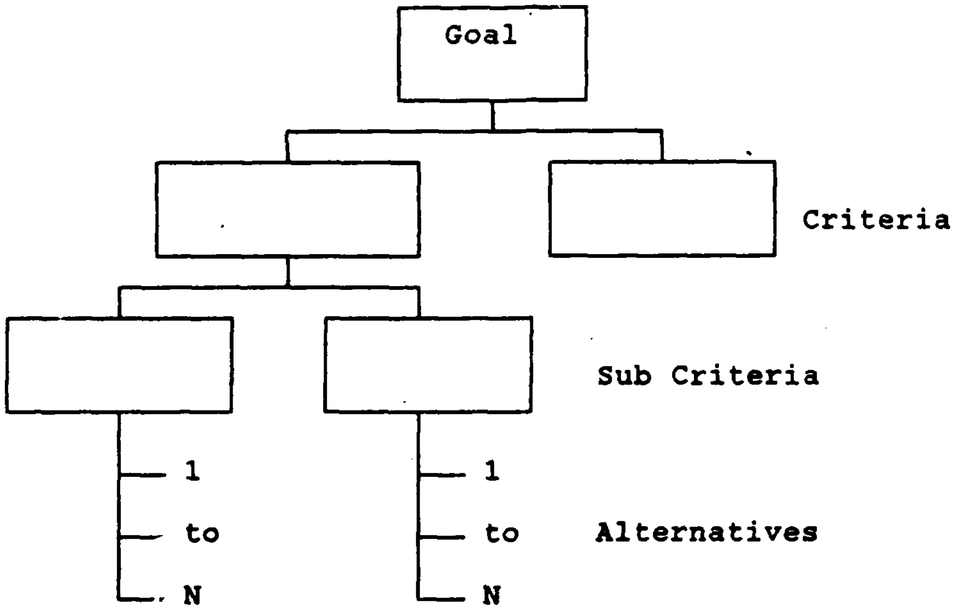


Figure 1. The Decision Hierarchy

prioritization lists to be considered. As a result, the structuring of the problem and the weighting of the nodes is accomplished by the special management office for R&M. These "experts" have the necessary skill and expertise to provide and coordinate the various portions of the tree with the decision makers and their staffs.

Prior to the application of AHP to this prioritization process, the manual process was too complex, and may have resulted in satisficing. Newell and Simon define satisficing as, "setting an acceptable level or aspiration level as final criterion and simply taking the first acceptable move (alternative)(Newell and Simon, 1972:681)." If satisficing

did result from the overwhelming complexity, poor funding priorities may have resulted to the extent that national security may have been impacted. Darko's treatment of AHP is a start, but the process is still much too cumbersome manually. It takes too much time to coordinate with the Joint Studies Group analysts, not to mention the amount of time required for mainframe computer support. TAF commanders need better response to make good prioritization decisions. This research, application of AHP on a microcomputer, affords the experts the flexibility to give fast, rational recommendations to the decision makers. The current effort differs from Darko's because it will provide a viable PC-based software tool for the SMO-R&M managers to use in making decisions.

Air Force "microcomputer acquisitions have increased tremendously since 1983 (Van Scotter, 1986:22)," states Captain James Van Scotter. With the availability of these microcomputers to most AF managers, computer software tools to effectively use these powerful tools in decision making are needed.

Evolution of Expert Support Systems

Computer software systems have evolved from simple office automation systems, electronic data processing, management information systems, to more complex decision support systems, expert systems, and expert support systems (see Table 2). Each of these software systems was designed, to accomplish certain tasks for specific management levels.

User	Software Systems
Top Management	Expert Systems, Expert Support Systems, and Decision Support Systems
Middle Management	Management Information Systems
First Line Management	Electronic Data Processing
Clerical Personnel	Office Automation Systems

Table 2. Software Systems

Once designed these software systems were made available to all users at any level, who could justify their particular requirement for computer support.

Clerical Personnel Needs. Office automation systems are those computer systems that facilitate office work, such as word processing. These systems were designed to automate routine office work for clerical personnel.

First Line Management Needs. Electronic data processing (EDP) was designed to process fundamental repetitive tasks found at this level in the organization. According to Sprague and Carlson, "EDP was first applied to lower operational levels of the organization to automate the paperwork (Sprague and Carlson, 1982:6)."

Middle Management Needs. Middle management needed the data integration of management information systems (MIS). MIS draw from various data bases to provide information needed by this level in the organization. These systems were designed with integration and information management in mind.

Top Management Needs. Many computer software systems are designed to facilitate this level in the organization. Beginning with decision support systems, and ending with expert support systems this research will briefly discuss each of these areas as they pertain to top management.

Decision Support Systems (DSS) are computer systems aimed at, "..quickly assisting managers in making effective decisions in those areas where both management, judgement, and computer analysis are required (Allen and Emmelhainz, 1984:129)." According to Dr. Richard E. Pesche in the book Military Logistics,

> "The emphasis of a DSS is on "customized support" for the decision maker. A DSS addresses four major concerns of the decision maker. These include:
>
> 1. SEMI-STRUCTURED TASKS - A DSS addresses semi-structured tasks which include explicit, well defined and algorithmic procedures as well as intuitive and subjective procedures.
>
> 2. SUPPORT - A DSS is intended to help the manager do his/her job.
>
> 3. EFFECTIVENESS - A DSS must be capable of identifying what should be done and assuring that the selected problem solving approach and criteria are relevant to the issue at hand.
>
> 4. EFFICIENCY - The DSS must be capable of performing a task as efficiently as possible in relation to a pre-established procedure (Westfall and others, 1987:502)."

An expert systems is defined as:

> "...a computer program that mimics a human expert; using the methods and information acquired and developed by a human expert, an expert system can solve problems, make predictions, suggest possible treatments, and offer advice with a degree of accuracy equal to that of its human counterpart (Allen and Emmelhainz, 1984:136)."

Expert systems coupled with elements of decision support systems form the basis for Expert Support Systems (ESS). Expert system knowledge bases are reservoirs of information consisting of logical relationships and deductive rules that affect the likelihood, preference, and characteristics of various outcomes under different conditions (Davis, 1988:64). Dr. Ernest H. Foreman makes a differentiation between ESS and ES. He states,

> "An Expert Support System differs from an Expert System in that the former is typically designed to support an expert where the latter is designed to replace an expert (Foreman, 1986:457)."

These are not subtle differences (see table 3). Expert support systems augment an expert during the chore for which it was designed -- in this case, our prioritization problem. Foreman further states:

Table 3. Expert Systems vs Expert Support Systems (Adapted from Foreman, 1986:457)

	Expert Systems	Expert Support Systems
Frequency of Problem	Frequently	One of a kind
Level of Expertise required	Up to Expert e.g. diagnosis, filling complicated forms	Beyond Expert e.g. strategic, policy
Benefit	Reduced costs Increased Speed	Better decisions Improve communication

> "Until recently, multi criteria problems were extremely difficult to deal with. However, with the advent of the Analytical Hierarchy Process (AHP) and the personal computer, multi-criteria problems can be addressed in a rational manner (Foreman, 1986:456)."

Expert Choice is an ESS designed by Dr. Foreman to augment experts in structuring and solving their problems. This software helps the decision maker perform the pairwise comparisons inherent in Saaty's AHP, and vital to the prioritization problem. The pairwise comparisons will be demonstrated in the next chapter. Expert Choice also has the ability to tie spreadsheets, text, and raw data to any specific node for documentation purposes.

Artificial Intelligence has not been discussed in this research because in this context, the ESS developed for this prioritization process is not considered AI.

Reliability and Maintainability Issues

Air Force reliability and maintainability issues are complex:

> "As we accumulate field experience with new weapon systems, it may become apparent that a system's R&M characteristics fail to meet expectations through misjudgment, mismanagement, changes in operating environment, or other unforeseen causes. This experience often leads to system modification proposals and projects so as to correct or enhance R&M characteristics (Westfall and others, 1987:400)."

Dr. Benjamin S. Blanchard defines reliability as:

> "... the probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified conditions (Blanchard, 1986:12)."

Department of Defense (DOD) Directive 5000.40 defines maintainability as:

> "The ability of an item to be retained in or restored to a specified condition when maintenance is performed having specified skill levels, using prescribed procedures and resources."

Class IV-B modifications are those mods that "modify to correct safety or R&M deficiencies (Tactical Air Command, 1987c:II-9)." Safety modifications (Class IV-A) are automatically given top priority, and therefore funded first. Class IV-B mods to implement R&M are the focus of this research.

HQ TAC/SMO-R&M is annually tasked to prioritize the TAF Class IV-B modifications (Tactical Air Command, 1986a:18; Tactical Air Command, 1988b:III-5; Tactical Air Command, 1987d:I-15). Data from two of HQ AFLC's data bases are required to establish funding priorities. The first data base, the Pacer Lab System, is required to provide cost information. The second data base is the Maintenance and Operational Data Access System (MODAS). This system provides information on the aircraft affected by the proposed modification (Yetter, 1988). Once all information from these data bases is retrieved by SMO-R&M personnel, it is arranged on modification worksheets (refer to Figure 3 chapter 4), and input into the AHP model operated by HQ TAC/JSG.

The Joint Studies Group analysts, in conjunction with the SMO-R&M experts, build the TAF decision hierarchy model as demonstrated in figure 2. This AHP-based model is designed to run on JSG's mainframe computer. Communication

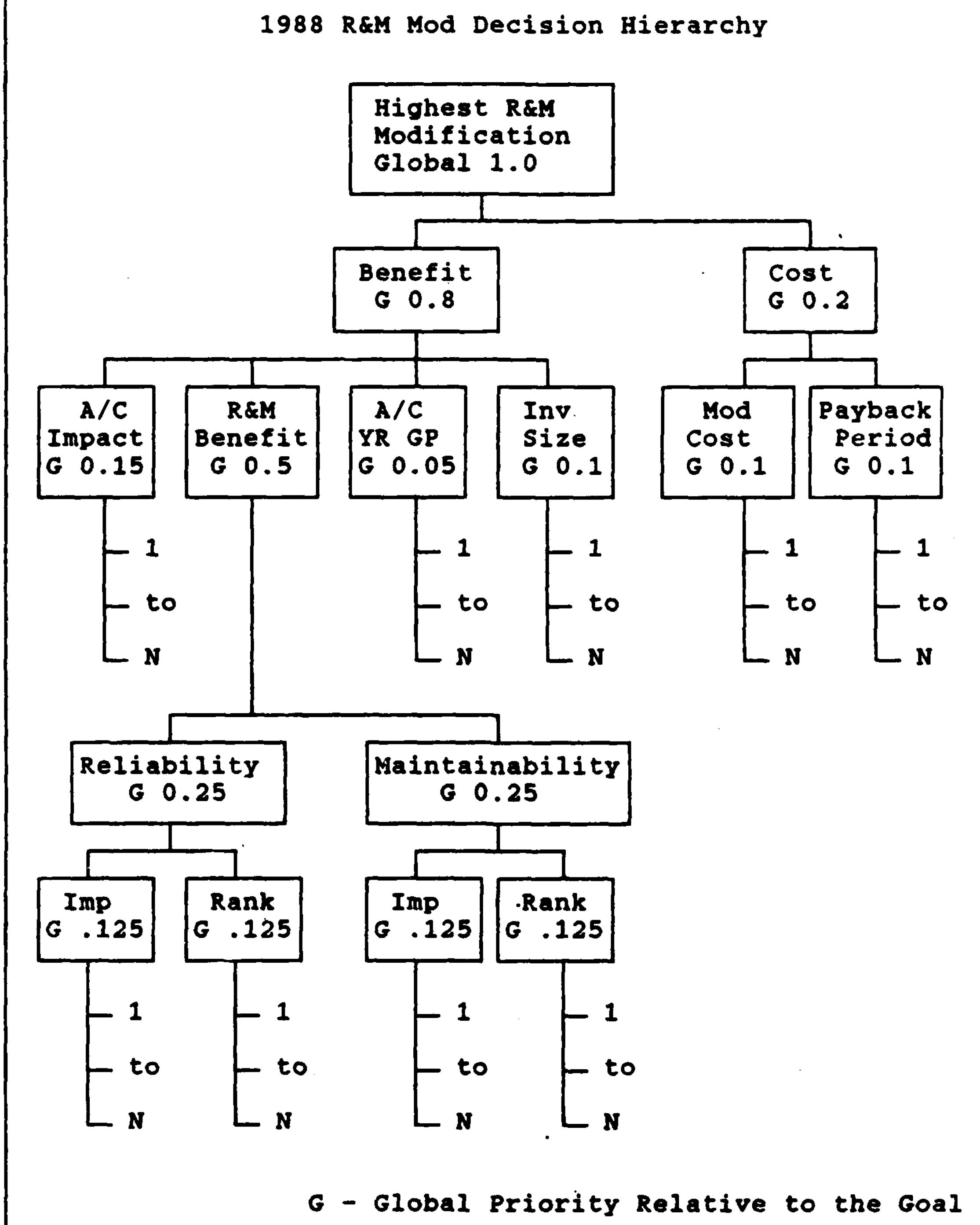


Figure 2. 1988 R&M Mod Decision Hierarchy

of the complexities of the decision processes between SMO-R&M and the computer analysts (JSG) is crucial to providing the decision makers with the best possible results. Once all the modification worksheet data is entered into the model, the model is executed. The resulting list of prioritized modifications is provided to SMO-R&M.

The final prioritized list is provided to the TAF commanders at the fall TAF commanders conference for approval. Once approved the list is sent to HQ AFLC to be considered when HQ AFLC combines the lists from the other major commands for HQ AFLC's POM submission. The list is also published in Volume II of the R&M 2000 Plan.

Headquarters AFLC uses a prioritization model known as HO40 to prioritize all Air Logistic Centers (ALC) proposals for modifications on all weapon systems in the AF inventory. This model was developed in 1979, to be used for budget purposes (Kalfas, 1988). The major commands along with the SPMs were not satisfied with the priorities of modifications based on the HO40's goal, i.e. funding executability. This means the lower cost modifications are given priority over more costly modification proposals. The model algorithm is also heavily weighted toward "Doability", that is, the probability that funds allocated will be obligated. The doability is often emphasized at the expense of user "desirability" and the easiest/cheapest modifications are done ahead of higher-priority, more critical mods (Tactical Air Command, 1986a:19). The MAJCOMs (the "users") and the

SPMs (the weapon system managers) argue that the performance measured goals should have the priority over funding executability considerations. HQ TAC's method of influencing this process is to collect all proposed modifications, prioritize the list, publish the list in the R&M 2000 Plan, and send the list to HQ AFLC.

HQ AFLC is working toward using the weapon systems master plan for the modification priorities proposals (Kalfas, 1988). Section 1 of the Weapon Systems Master Plan document contains the prioritized list of all modifications for the weapon system. The weapon system master plan is coordinated between the SPMs and the MAJCOMs (Witherell, 1988). Once coordinated this document presents a "united voice" to Headquarters Air Force providing the direction for the weapon system management (Kalfas, 1988). HQ AFLC is still concerned with the ability of the proposed modifications to be able to begin once funding becomes available. This proposed change, the usage of the weapon system master plan, will occur once all MAJCOMs and SPMs agree on the prioritization procedure in the coordination process. It is hoped that the author's AHP based modification prioritization expert support system will be adopted or will play a part in the proposed change.

The Air Force Reliability and Maintainability Policy, AFR 800-18 describes the operational R&M goals. Listed in order of priority the goals are:

a. Increase Combat Capability. Increase operational capability, sustainability, suitability, and

probability of mission success by acquiring systems that break infrequently and are easily and quickly repaired.

b. Increase the survivability of the combat support structure. Reduce or eliminate elements of maintenance and support structure subject to attack and destruction, and improve the ability of the unit to disperse for survivable operation.

c. Decrease mobility requirements per unit. Reduce or eliminate airlift requirements for deploying units, and support requirements for ground mobile units.

d. Decrease manpower requirements per unit of output. Ensure that systems can be operated and maintained with minimum personnel, specialties, and skill levels.

e. Decrease costs. Decrease R&M-driven costs (Department of the Air Force, 1986a:1).

Along with the R&M 2000 goals R&M priorities are outlined in AFR 800-8.

Air Force Regulation 800-8, Integrated Logistics Support (ILS) Program states that "Reliability, maintainability, and supportability requirements and related resources must be considered with cost, schedule, and performance requirements (Department of the Air Force, 1986b:1).

When designing the decision hierarchy the model builders must consider both of these regulations. Criteria and subcriteria must be weighted to give the appropriate measure of conformance to these directives.

Summary

This chapter presented many diverse subjects with a common thread of purpose. That purpose was the basis of this research - to develop a microcomputer-based expert support system, while applying the analytic hierarchy process to

prioritize HQ TAC/SMO-R&M's Class IV-B modifications. Though not a totally encompassing literature review on any one of the relevant subjects, the subjects were treated as they pertain to this research.

The next chapter will describe the methodology used in this research to study the complex decision making process HQ TAC currently accomplishes.

III. Methodology

Overview

This chapter will describe a complex decision process and an expert support system developed to structure and solve the research problem. The research specifically addresses the complex decision of prioritization that HQ TAC faces. Annually HQ TAC/SMO-R&M prioritizes the Class IV-B modifications for the TAF. This prioritized list then is sent to HQ ALFC to be combined with other major air commands lists for the POM submission. This is HQ TAC's method of influencing HQ AFLC on how modification money designated for TAF aircraft should be spent. This chapter will describe the general research methodology and HQ TAC's process to gather the information.

Research Design

The research design used for this project is Action Research. The purpose of this design is:

> "To develop new skills or new approaches and to solve problems with direct application to the classroom or working world setting (Isaac and Michael, 1978:27)."

Action Research has many advantages over other research designs. This research will have direct application to the working world and will also provide an "...orderly framework for the actual observations used to develop and solve the problem (Isaac and Michael, 1978:45)." Allowing changes to be made during the process, this design is "...flexible and

adaptive to the changing needs of the user (Isaac and Michael, 1978:45)", and does not relegate the research to a rigid structure.

The Action Research design is limited in generalized application, as well as external and internal validity due to the small sample size used in this research. With only one organization responsible for this prioritization process, the effects of the ESS may not be generalized to other organizations which may be using the same or similar processes. The one-group pretest-posttest design discussed by Campbell and Stanley was not chosen for this research because the lack of data points for the posttest would not allow statistical inference to be made to the general population (Campbell and Stanley, 1960:45).

HQ TAC's Process

The following is a discussion of Headquarters TAC's decision making process in the arena of Class IV-B mod prioritization, observed by the author on a trip to Langley AFB, Virginia in June 1988.

SMO-R&M's goal in producing a TAF commanders approved list of modifications is to influence and defend mods as they are listed on the AFLC (HO40) composite list in their POM submission and in the HQ TAC R&M 2000 Plan Volume II (Collins, 1988a). The objectives are to:

1. Offset the bias of executability imposed by the HO40 Model and keep the users' need in focus.
2. Be a readily available tool for Headquarters Air Force to consult when going through budget change

exercises. Allows the office to better defend or have an opportunity to defend the high priority mods (Collins, 1988b:1).

Annually HQ TAC is the focal point for acquiring the information necessary to prioritize the TAF Class IV-B modifications. The Special Management Office for Reliability and Maintainability (SMO-R&M) at HQ TAC has the responsibility to gather, coordinate, prioritize, and submit the TAF commanders approved list to HQ AFLC. This list is then used in the HQ AFLC POM submission and Volume II of the R&M 2000 Plan.

The process begins when HQ TAC/SMO-R&M requests the field to submit all of their modification requirements. This is done by a message requesting the TAF organizations submit all known modifications.

The special project manager (SPM) for a particular weapon systems may elect to prioritize his or her own list of modifications to influence the SMO-R&M prioritization. The F-16 and the F-15 SPMs have stated they will prioritize their modification lists before submission to HQ TAC. Once submitted, the mod list to SMO-R&M will be rank ordered in the model as the SPM requested.

Once all mod requests are received by message or through the SPM's, mod worksheets (see figure 3) are filled out for each mod by SMO-R&M. Each of the data elements on the mod worksheet is described below:

1. Aircraft Impact: Based on expected performance of the mod to avert a possible aircraft grounding situation.

User/SPM Ranking ________

SHORT TITLE: ________________________________

MOD NUMBER: ________________________________

DESCRIPTION: ________________________________

____

____

1. Does this mod avert a possible aircraft grounding situation (High, Medium, Low or No potential): ________

2. Reliability Improvement: G063 MTBM Predicted/Current
   Predicted: ________
   Current: ________ Ratio: ________

3. Reliability Ranking Factor: (G063 MTBM Current Data) ________

4. Maintainability Improvement: (G063 Current Data) ________

5. Maintainability Ranking Factor: (G063 MMH/FH Current Data) ________

6. Aircraft Year Group: (Mean production Year for Group of Affected Aircraft) ________

7. Inventory Size: (Number of Aircraft Affected) ________

8. Mod Cost: (AFLC Pacer Lab P3B Data - Total) ________

9. Payback Period: (Is there an amortization schedule) ________

OTHER REMARKS: ________________________________

____

____

____

Figure 3. Mod Worksheet

2. Reliability Improvement: Ratio of predicted mean time between maintenance (MTBM) versus current G062 MTBM data found on the MODAS data base. The greater the predicted improvement, the greater the benefit realized.

3. Reliability Ranking Factor: Measure of how poor the reliability of a system/component is as compared to all systems that make up the weapon system, i.e. a measure of "hurt". Therefore, the higher the ranking factor (percentile), the greater the need to demonstrate improvement for the existing system.

4. Maintainability Improvement: Predicted maintainability improvement for the system, the greater the improvement the greater the benefit realized. Reflects increased aircraft time and fix rate.

5. Maintenance Ranking Factor: Measure of how poor the maintainability of a system/component is as compared to all systems that make up the weapon system, i.e. a measure of the high man-hour drivers that are "eating your lunch." Therefore, the higher the ranking factor the greater the need to demonstrate improvement for the existing system.

6. Aircraft Year Group: Based on the mean production year for the group of effected aircraft. Savings accrue longer for improvements and impact of improvements are more lasting.

7. Inventory Size: Based on the number of units in service. Cost of mod is lowered by distributing developmental costs of over a larger base. Cost savings through improvement proved R&M increases with size of inventory involved.

8. Mod Cost: Based on AFLC Pacer Lab data base P3B data, reflects the total cost of the mod including spares and support equipment.

9. Payback Period: Time required to offset money expended to benefit from the mod is realized. The sooner the payback the better (Collins, 1988a).

These data elements are directly related to the R&M 2000 goals explained in the last chapter. The data elements and how they relate are as follows:

1. Aircraft Impact: Should an aircraft fleet or weapon system not receive the benefits of the modification

and become unusable (grounded), combat capability of the weapon system is naturally negatively affected.

2. Reliability Improvement: This directly impacts the combat capability of the aircraft or weapon system the modification is intended for.

3. Reliability Ranking Factor: The ability of a weapon system to perform as required is a factor of mission capability and combat capability.

4. Maintainability Improvement: Reduction of the amount of time required to fix an aircraft places the aircraft back to a mission capable status quicker impacting combat capability.

5. Maintenance Ranking Factor: Reducing the highest probable failure item on an aircraft will improve the combat capability of the entire aircraft fleet.

6. Aircraft Year Group: A function of improving the weapon system that will receive the greatest overall benefits from the modification will impact not only the cost considerations, but may decrease the number of men required to service the aircraft for the LCC.

7. Inventory Size: Improving the largest number of aircraft will demonstrate the greatest cost savings and greatest manpower reduction.

8. Modification cost: While the greatest benefit is the desired goal the total mod cost is considered in the model but not a function of the R&M 2000 goals.

9. Payback Period: The amortized period where benefits from the mods are realized, following the costs expended.

While not all mod proposals will have the maximum R&M 2000 impact, all proposals that can be demonstrated to have savings in any of these areas are rewarded in the model.

Information is then gleaned from two of AFLC's information data bases and added to the worksheets. The first data base is the P3B exhibit from the Pacer Lab Data Base System. The second is the Maintenance and Operational Data Access System (MODAS) data base, referred to as G063

data. The mod worksheets with the data elements required to make the decision are then submitted to the Joint Studies Group (JSG) at HQ TAC for their computer analysis.

The structuring of the problem in the form an analytic hierarchy (referred to after this as the 1988 R&M Mod Decision Hierarchy (see figure 4)), is the task of the experts in SMO-R&M along with the analysts in JSG. They prioritize the criteria and the subcriteria for each node of the hierarchy that the decision makers will require using the pairwise comparison technique (Schooff, 1983). Benefit is compared to cost; aircraft impact is compared to aircraft year group, inventory size, and R&M benefit; modification cost is compared to LCC; reliability improvement is compared to reliability rank; and maintainability improvement is compared to maintainability rank. Based on the judgement of the experts mentioned above, the 1988 model was designed with benefits four times more important than cost (0.8 to 0.2) (refer again to figure 4). Under the benefit portion of the hierarchy, aircraft impact (A/C Imp) was factored three times that of aircraft year group (A/C Yr Gp)(0.15 to 0.05); Inventory size (Inv Size) was given twice the importance of A/C Yr Gp (0.1 to 0.05); and R&M benefit was ten times that of A/C Yr Gp (0.5 to 0.05). Under the R&M benefit, reliability and maintainability were ranked equally with an overall value of 0.25. Improvement and rank under both reliability and maintainability were equally factored and given specific weights of 0.125 each. Under the cost portion

1988 R&M Mod Decision Hierarchy

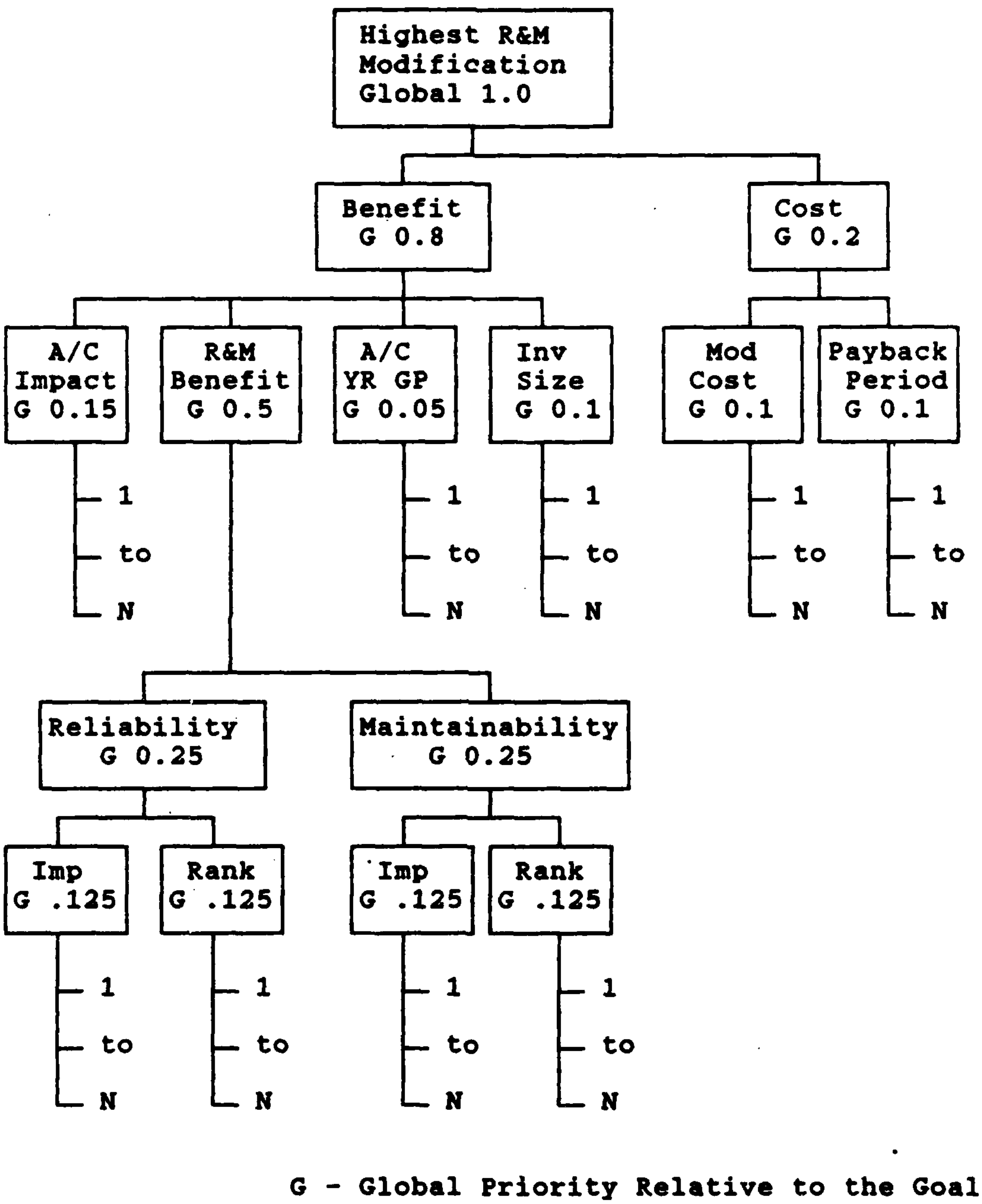


Figure 4. 1988 R&M Mod Decision Hierarchy

of the hierarchy, modification cost (Mod Cost), and payback period were given equal weights of 0.1. A decision hierarchy using Dr. Thomas L. Saaty's analytic hierarchy process (AHP) is used by the JSG to order the problem and derive a solution (Collins, 1988a).

Each of the TAF organizations is then sent the prioritized list to coordinate with the respective commands. The feedback gained from these commands on their mods ensures that no mods are inadvertently left off the final list or that priorities are not grossly in error.

Briefings are then prepared by the SMO-R&M personnel for the fall TAF commanders conference. Since each command has already coordinated the prioritization process through the respective chain-of-command, approval of the list is simplified.

HQ TAC/SMO-R&M submits the list to HQ AFLC and publishes Volume II of the R&M 2000 Plan.

HQ TAC's Improvements

At the 1987 TAF commanders conference the commanders made pairwise comparisons for each of the decisions for all the proposed Class IV-B mods, using the analytic hierarchy process, based on manual and mainframe methods. Mod 1 was compared to mod 2, 3, 4, 5, ... N (some number of modifications), then mod 2 was compared with mod 3, 4, 5, ... N, etc., for the entire list of modifications. This process proved to be very time consuming for the general officers who were making these decisions. The 1988 process was simplified

due to efforts by the Chief of the Maintenance Division HQ TAC/SMO-R&M (one of the "Experts" mentioned earlier). The model used previously was reevaluated using only objective data from P3B, and G063 data. This discussion is amplified in the validation portion of the next chapter. This improvement allows a more objective assessment of the prioritization process and provides ease of model use. The prioritization decision listing resulting from the previous model (1987) was duplicated using only this objective data, thereby validating the new method.

Using this as a baseline for the 1988 model, the revised mod worksheet shown earlier reflects only those data elements and one additional data element, Aircraft Impact. (The rational for this item is that the weapon system that will experience a grounding situation should the mod be delayed, should be given additional priority to improve the ranking of the modification in the process.)

The objective data from the mod worksheets is input into the approved model by HQ TAC/JSG, and the resulting list is provided to the TAF commanders for their approval. Once approved, the list is then sent to HQ AFLC and published in Volume II of the R&M 2000 Plan.

Though this is an improvement to last year's process, this method requires additional computer analysts support along with the use of a costly mainframe computer. Inherent with this process is an unnecessary amount of time to incorporate a change to the model or correct the data.

As demonstrated in the next chapter, flexibility is the key to the improvement to the process designed by this author. Through software available for the microcomputers already in the SMO, the process will be readily modified without the need for additional support from the Joint Studies Group at Headquarters TAC.

Summary

This chapter discussed the rationale for using Action Research as the preferred method to research this process. This method of research allows flexibility in the research design while developing solutions for "real world" applications. Also discussed in this chapter, was the process HQ TAC uses to prioritize the Class IV-B modifications. While the improvements made by the Chief of the Maintenance division for SMO-R&M for this year's model are a step in the right direction, more can be done. The ability of the process to be placed on a PC will greatly enhance the ability of the managers to make responsive changes giving the decision makers remarkable flexibility. In addition, the decision makers will benefit from the proposed improvements to the process, specifically the savings of time and resources discussed in the next chapter.

IV. Results and Discussion

Overview

This chapter discribes the author's improvements to the TAF Class IV-B prioritization process, development and implementation of an ESS, and validation of this entire process. Finally, a general discussion of the benefits derived from the research is also presented.

The Process

An expert support system was designed by the author using Expert Choice, developed by Decision Support Software. The author developed a three step approach to solve the research problem. The first step was to develop a spreadsheet to analyze the input data. Entitled the data Analysis Spreadsheet, it contained the raw data from the mod worksheets. Figure 5 contains sample data from HQ TAC. Data elements (across the top of the columns) are as follows:

1. Aircraft Impact (A/C Imp)
2. Reliability Impact (Rel IMP)
3. Reliability Rank (Rel R)
4. Maintainability Impact (M I)
5. Maintainability Rank (M R)
6. Aircraft Year Group (A/C YR GP)
7. Inventory Size (Inv Size)
8. Modification Cost (Mod Cost)
9. Payback Period

Mod names are shown at the left of the figure. The graph function in the spreadsheet software allowed the data to be plotted in a scatter-gram. The individual data elements from each mod worksheet were plotted in the graph portion of the

Figure 5. Data Analysis Spreadsheet

Mod Name	SPM	1	2	3	4	5	6	7	8	9
				Data Elements						
1. F15EID	1	4	8.33	16.56	.26453	9.24	1979	801	26.03	Yes
2. F16MBC	1	3	13.4	57.55	.20699	8.21	1981	1278	33.02	No
3. A10SEC	1	1	29.4	38	.17234	17.1	1979	274	.357	No
4. A7CFS	1	2	0	10.34	.0023	8.15	1979	20	4.65	Yes
5. F111EMS	2	3	0	9.29	.18	13.8	1971	277	86.87	No
6. GENG	1	4	3	24.12	2.719	100	1983	1200	17.8	Yes
7. .										
8. .	etc.									
9. .										

spreadsheet software to determine the range of the data and whether data points were clustered in such a way as to allow for a subdivision into data ranges. These graphs were used to identify "natural" break points and develop the data ranges. Data ranges were then extrapolated from the resulting graphs for each of four ranges used by the author and a table (see table 4) was created for rating each mod on all of the data elements. Once defined, these data ranges were used to identify a numeric value from one (below average) to four (outstanding) for each of the data elements on the worksheets.

The second step in the process was to replicate the 1988 TAF prioritization process described in the last chapter, using the microcomputer-based ESS Model developed by the author (see figure 6). Notice figure 6 is very similar to figure 4 in chapter 3. The SMO-R&M experts designed the

Table 4. Data Ranges

	Criteria	Below Average	Average	Above Average	Out-standing
1.	A/C Impact	(Based on the experience of SMO-R&M)			
2.	Rel I	0 - 0.49	0.5 - 1.99	2 - 9.9	> 10
3.	Rel R	0 - 9.9	10 - 20	21 - 49	> 50
4.	M I	0 - 0.05	0.06 - 1.5	1.6 - 2.4	> 2.5
5.	M R	0 - 4	4.1 - 9.9	10 - 17	> 18
6.	A/C YR GP	< 1978	1979 - 1980	1981 - 1982	> 1983
7.	Inv Size	0 - 250	251 - 699	700 - 1199	> 1200
8.	Mod Cost	> 500	499 - 101	100 - 16	< 15
9.	Payback Period	No (Amortized or Not)			Yes

hierarchy for the 1988 model and assigned the respective weights for the criteria and subcriteria. This entire process was duplicated precisely in the author's ESS model.

The only difference in the two models is how the large number of alternatives are manipulated. In the 1988 model, the mainframe computer manipulated the data. The Expert Choice ESS model, run on a microcomputer, was limited in memory capacity available. Four alternatives were evaluated at the alternatives level for each of the data elements and each mod was assigned a rating from "Below average" to "outstanding" (arithmetically 1.0 to 4.0) for each element. (see Figure 6 and refer to Appendix A)

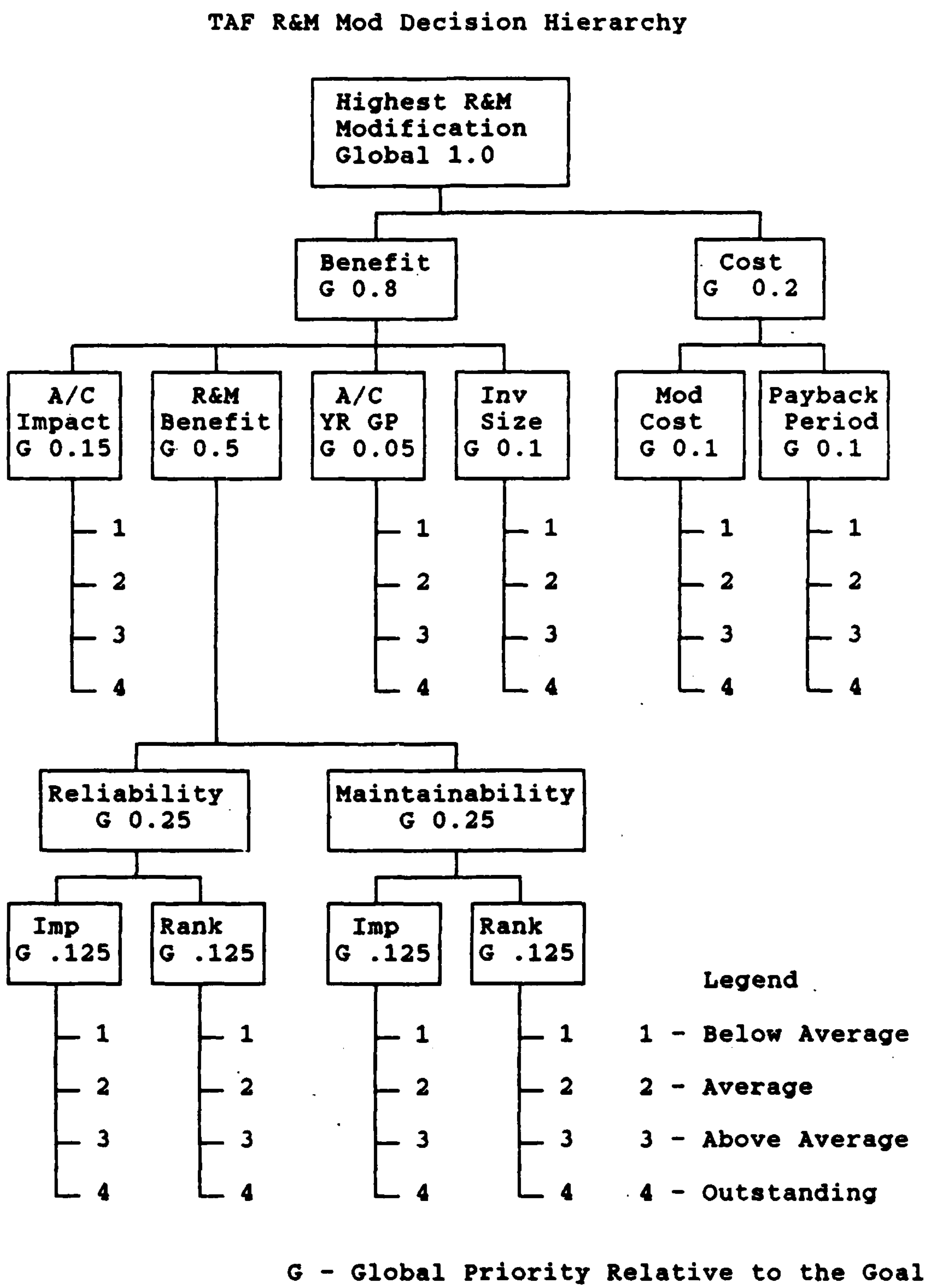


Figure 6. ESS Model

For the third and last step, the author developed another spreadsheet that would accumulate the points awarded to each modification for each of the data element, and sort the entire list of modifications. This spreadsheet, designated as the TAF Class IV-B Mod Spreadsheet, was arranged with IF .. Then .. Else statements to place the values for each of the data elements (see figure 7). The numbers derived from the synthesis of the entire model (see Appendix B) were entered into the spreadsheet and the numeric values (1.0 associated with below average etc.) were totaled into a specific column for that purpose. For example: If the Inventory Size data element of a particular modification proposal were rated 1.0 from the data ranges (Table 4) the spreadsheet would assign a value of 0.006 to the total column; a rating of 2.0 would add 0.012; a 3.0 would add 0.027; and a rating of 4.0 would add 0.057 to the total column (refer to Appendix B for derivation of the synthesis

Figure 7. TAF Class IV-B Mod Spreadsheet

	Mod Name	Total	SPM	1	2	3	4	5	6	7	8	9
1.	F15EID	.312	1	4	3	2	4	2	3	3	3	3
2.	F16MBC	.378	1	3	4	4	3	2	3	4	3	4
3.	A10GBAS	.281	1	3	1	4	2	4	1	2	4	1
4.	A7CFS	.083	1	2	1	2	1	2	1	1	1	1
5.	F111EMS	.152	2	3	1	1	3	3	1	2	2	1
6.	Geng	.414	1	4	4	3	3	4	4	4	3	2
7.	.											
8.	.	etc.										
9.	.											

values used here). The sorted list was then compared to the 1988 TAF model results. The mnemonic name associated with each of the proposed modifications allowed consistent tracking of the mods between the two spreadsheets, the mod worksheets, and the ESS model. See Appendix A and B for graphical illustration of the ESS model and numeric values provided by synthesis of judgments to each data element.

Once all the mods were ranked and entered into the TAF Class IV-B Mod Prioritization spreadsheet, it was a simple matter to sort the spreadsheet using the total column to produce a rank ordered mod listing.

Validation

Although there are known limitations to action research with inferences to a general population, validation of the model was possible. The most notable validation of the model is that TAC is actually planning to implement the author's ESS immediately. The new methodology (the ESS model), will be used to provide decision makers with a prioritized list. This in and of itself is an important "validation" of the process.

The proposed process was also evaluated by the Chief of the Special Management Office for R&M. He was convinced that the process would save a considerable amount of time, manpower, mainframe computer time -- and therefore money.

In addition, the improved process was described and demonstrated to the Joint Studies Group at HQ TAC. They were responsible for the programming of the original model that

was used in the past. This model used AHP and provided the decision makers with the ability to make the pairwise comparisons necessary (in the previous model) to rank order the mods, but was mainframe-based and inflexible. The Chief analyst responsible for the JSG effort was impressed with the ease and flexibility of the modeling environment using ESS. Following the demonstration, the JSG analysts discussed the potential for the PC-based ESS and they confirmed the author's belief that the new method would solve the problem without the use of a mainframe computer support (Schooff, 1988).

The JSG analyst used the structure of the 1988 model to validate the process using five mods from the 1987 effort (see figure 8). The resulting prioritized list using the mainframe AHP model provided the same results as was derived through the process used by the decision makers in the 1987

Figure 8. Mod (1987) Priorities

Mod Name	1	2	3	4	5	6	7	8	9
16RDRI	2	2.1	41	1.37	3	1983	1278	4.27	No
16BATC	1	13.4	1	241	28	1983	1278	609	No
16FDR	1	0	100	0	0	1983	1278	227	No
16CSDG	1	15.8	>100	22.5	33	1983	1278	499	No
16RLG	1	15.2	7	4	10	1983	1278	91.4	No

Ratings

16RDRI	2	1	3	1	1	4	4	1	1
16BATC	1	3	4	4	2	4	4	1	1
16FDR	1	1	1	1	1	4	4	1	1
16CSDG	1	4	1	2	3	4	4	1	3
16RLG	1	1	4	3	1	4	4	3	3

Figure 9. Validation

Nod Name	Total	1	2	3	4	5	6	7	8	9
16BATC	.267	1	3	4	4	2	4	4	1	1
16RLG	.185	1	1	4	3	1	4	4	3	1
16CSDG	.173	1	4	1	2	3	4	4	1	1
16RDRI	.143	2	1	3	1	1	4	4	4	1
16FDR	.063	1	1	1	1	1	4	4	1	1

process. These same five mods were worked into the author's ESS model and the resulting list was the same as that derived in the previous two methods (see figure 9).

To sum, the process was validated three ways: the first was through intended use in an operational Air Force unit; the second by the JSG computer analysts that were previously responsible for the process; and last by a data trial using data from last year's process.

Discussion

There are many benefits to using the analytic hierarchy process approach to problem solving, and for implementing the AHP process on a micro-computer. The first is inherent with the defining and ordering of the problem. The problem, once structured, is less complex. Merely taking the time to structure the problem provides insight into the inexact way the typical decision is made.

The second benefit has to do with focusing the attention to a portion of the larger problem. This allows simpler, better defined responses to a problem. The process is

similar to the problem of how to climb a mountain. One starts the climb with the first steps and progresses with each additional step. To observe the entire mountain the mind cannot fathom how to progress - but broken down and visualizing each step, the process is less overwhelming.

Finally, the ability to document portions of the decision process allows replication of the process. Should the decision be questioned at any time the ability of the decision maker to document and replicate the process is invaluable.

Summary

This chapter has described the improvements the author has made to TAC's prioritization process. The expert support system is a simple process for solving a difficult problem. Prior to expert support systems like this one, decisions were often based largely on political factors. Traditional techniques used to solve these nonprogrammed decisions are to use judgments, intuition, creativity, and rules of thumb. Clearly with multiple criteria and more subcriteria these techniques are not adequate when one considers that millions of tax dollars are obligated based on the decision.

The ESS developed by the author encourages a more rational approach, yet still capitalizes on traditional approaches. The difference is in the visibility afforded into all factors that influence the decision. And the resulting efficiency introduced into the decision making process has great cost-saving potential.

V. Recommendations

Overview

Headquarters TAC/SMO-R&M is attempting to implement a methodology that will reduce the amount of time needed by the top echelons of Air Force managers to make quality decisions. These decision makers need a decision making tool to help them cope with complexity, make rational decisions within that context, and defend their decisions to others whose modifications will not be funded. Currently the process is accomplished on a mainframe computer operated by HQ TAC Joint Studies Group. Their computer is not dedicated solely to the prioritization of the Class IV-B modifications. With the methods and techniques discussed in this research the prioritization process could be accomplished on a microcomputer located in the HQ TAC/SMO-R&M office. By using current in-place equipment, with no additional manpower requirements, the prioritization process is simplified, more flexible, and more responsive.

Recommendations

Further research is needed to insure validation of this process. Using only one organization as a test case resembles the one-shot case study methodology with its known threats to both internal and external validity. While this study, using action research methodology, does not attempt to overcome validity problems, neither does it claim to be

generalizable. However, it is the author's belief that expert support systems can lead to improved decision making. More organizations and further modeling processes are needed to validate this claim. It is the opinion of those involved with this research that there are many opportunities to appply these techniques to other applications, once knowledge about the process is gained. Many organizations are responsible for making complex decisions. With budget limitations a reality many complex decisions involve limited resources. Expert support systems could be helpful to many organizations striving to "do more with less."

Other techniques to allow multiple alternatives using Expert Choice came to the attention of this author at the end of this research. Later versions of Expert Choice allow the ESS to handle a large number of alternatives without the need to use the external spreadsheets. This would have greatly simplified this project. More research is needed to determine if this is a viable method of prioritizing these modifications. Alas, there was interest, but not time to develop these techniques.

Summary

This research was intended to demonstrate that complex prioritization decisions can be handled easily by a PC with inexpensive software. Air Force managers and leaders, using the demonstrated software, can make flexible, reliable, and responsive decisions even in the nonprogrammed decision

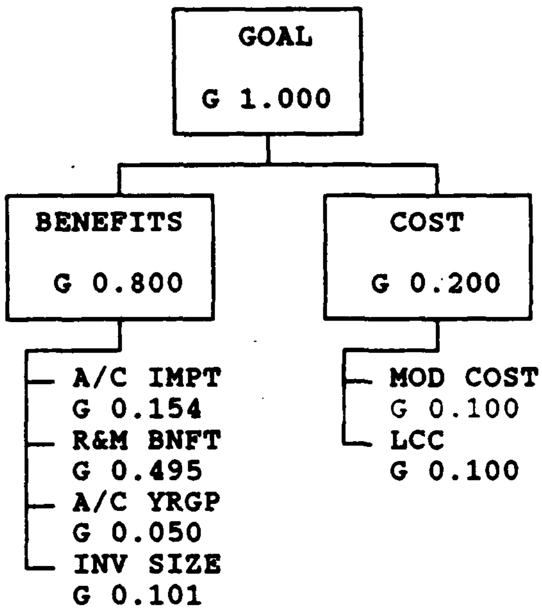
environment. Dr. Herbert Simon stated in his 1965 work, The Shape of Automation,

> "With operations research and electronic data processing we have acquired the technical capacity to automate programmed decision making and to bring into the programmed area some important classes of decisions that were formerly unprogrammed. Important innovations in decision-making processes in business are already resulting from these discoveries.
>
> With heuristic programming, we are acquiring the technical capacity to automate nonprogrammed decision making. The next two decades will see changes in business decision making and business organization that will stem from this second phase in the revolution of our information technology. (Simon, 1965:92)."

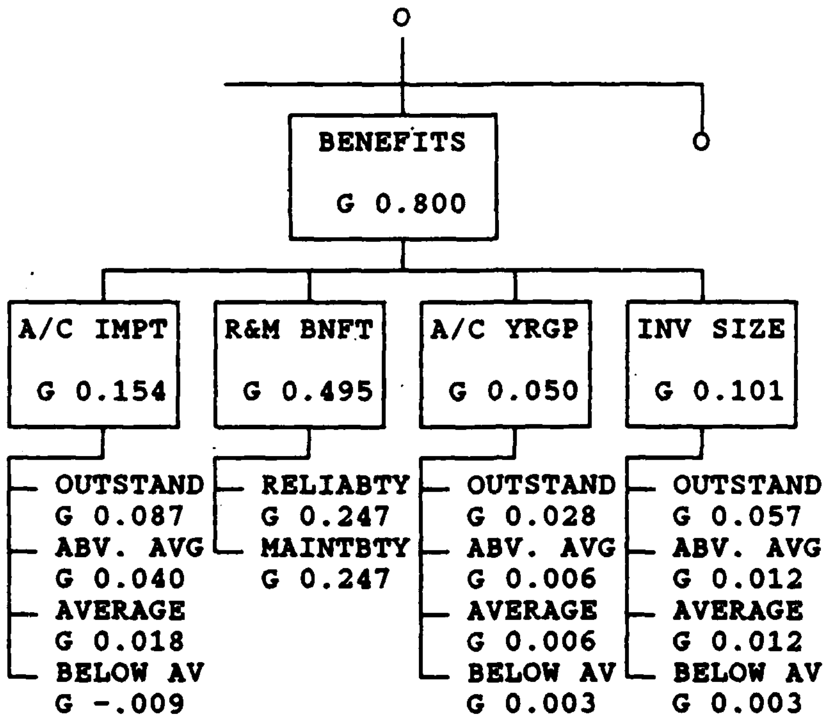
Simon was not far off in his time assessment. Similar to private-sector business leaders, AF managers and leaders face complex decisions in a constantly changing environment. The use of computer tools like the expert support system described in this research can use available Air Force resources, improve responsiveness, increase flexibility of the process, and improve the reliability of the decision making process.

Appendix A: <u>Expert Choice ESS Model</u>.

Select the mods with the highest R&M improvement.

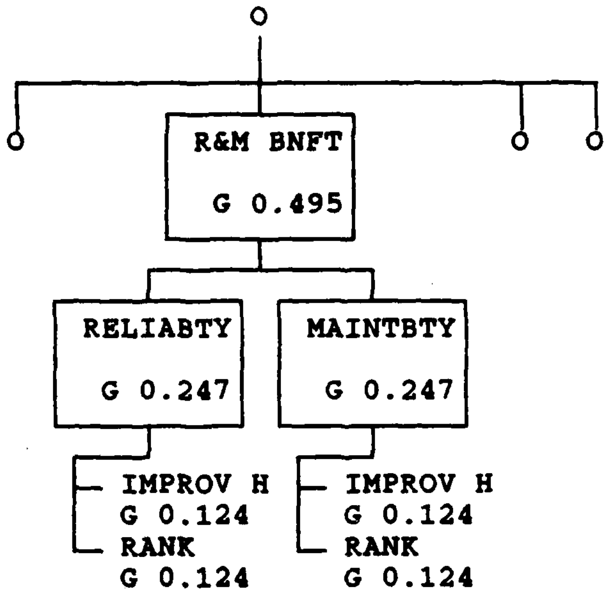


LCC	--- Life cycle cost - Amortized or not?
COST	--- Cost of the total projected modification.
A/C IMPT	--- Impact on the mods with the most R&M improvement
A/C YRGP	--- Aircraft Year Group.
BENEFITS	--- Gained by the Modification.
INV SIZE	--- Aircraft Inventory Size.
MOD COST	--- Total Dollar Amount Projected.
R&M BNFT	--- Reliability and Maintainability benefits.
G	--- GLOBAL PRIORITY: PRIORITY RELATIVE TO GOAL



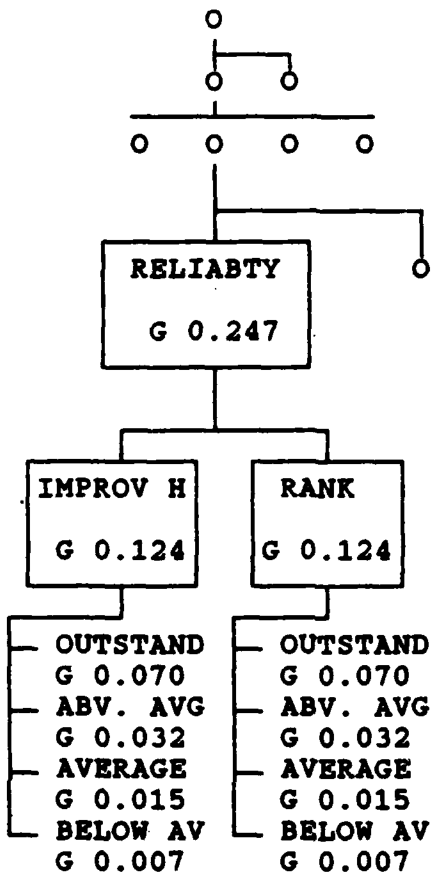
A/C IMPT --- Impact on the Aircraft Fleet.
A/C YRGP --- Aircraft Year Group.
ABV. AVG --- Above Average Attributes.
AVERAGE --- Average Attributes.
BELOW AV --- Below Average Attributes.
BENEFITS --- Benefits gained by the Modification.
INV SIZE --- Aircraft Inventory Size.
MAINTBTY --- Maintainability factors.
OUTSTAND --- Outstanding attributes.
R&M BNFT --- Reliability and Maintainability Benefits.
RELIABTY --- Reliability Factors.

G --- GLOBAL PRIORITY: PRIORITY RELATIVE TO GOAL



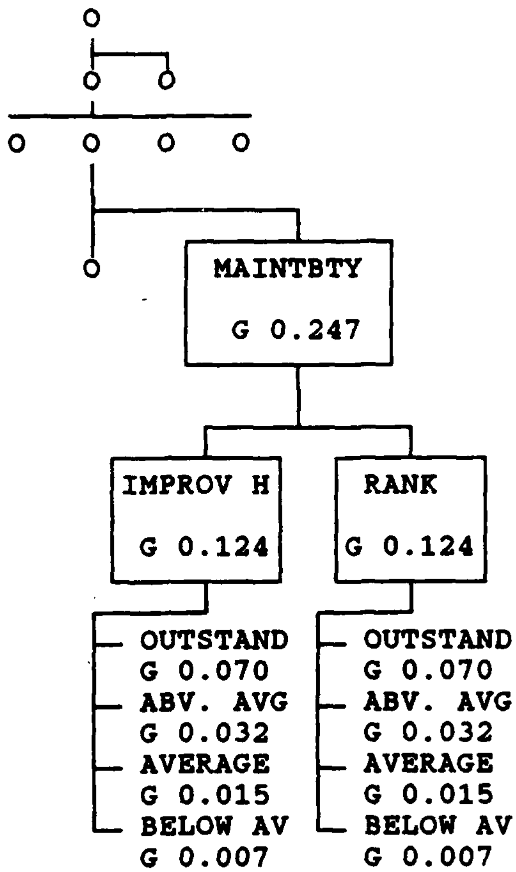
RANK --- Rank given in MODAS.
IMPROV H --- Improvement Hours.
MAINTBTY --- Maintainability Factors.
R&M BNFT --- Reliability and Maintainability Benefits.
RELIABTY --- Reliability Factors.

G --- GLOBAL PRIORITY: PRIORITY RELATIVE TO GOAL



RANK --- Rank Given in MODAS.
ABV. AVG --- Above Average Attributes.
AVERAGE --- Average Attributes.
BELOW AV --- Below Average Attributes.
IMPROV H --- Improvement Hours.
OUTSTAND --- Outstanding Attributes.
RELIABTY --- Reliability Factors.

G --- GLOBAL PRIORITY: PRIORITY RELATIVE TO GOAL



RANK --- Rank Given in MODAS.
ABV. AVG --- Above Average Attributes.
AVERAGE --- Average Attributes.
BELOW AV --- Below Average Attributes.
IMPROV H --- Improvement Hours.
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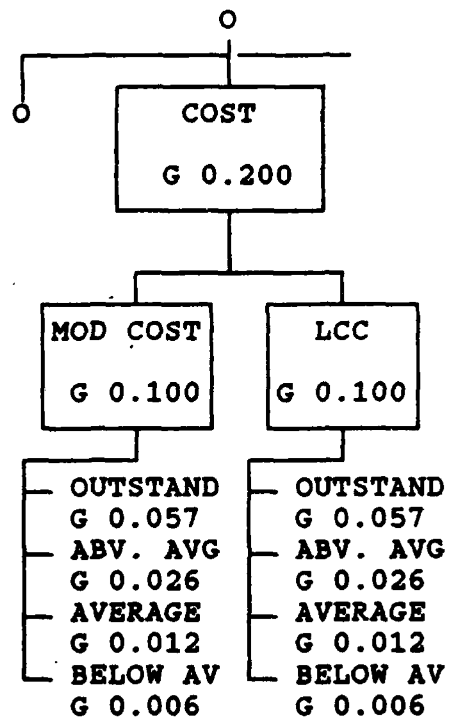

LCC --- Life Cycle Cost - Amortized or not?
COST --- Total Cost of the Projected Modification.
ABV. AVG --- Above Average Attributes.
AVERAGE --- Average Attributes.
BELOW AV --- Below Average Attributes.
MOD COST --- Total Dollar Amount.
OUTSTAND --- Outstanding Attributes.

G --- GLOBAL PRIORITY: PRIORITY RELATIVE TO GOAL

Appendix B: Synthesis of the ESS Model.

Select the mods with the highest R&M Improvement.

TALLY FOR SYNTHESIS OF LEAF NODES WITH RESPECT TO GOAL

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
BENEFITS = 0.800				
	R&M BNFT = 0.495			
		RELIABTY = 0.247		
			IMPROV H = 0.124	
				OUTSTAND = 0.070
				ABV. AVG = 0.032
				AVERAGE = 0.015
				BELOW AV = 0.007
			RANK = 0.124	
				OUTSTAND = 0.070
				ABV. AVG = 0.032
				AVERAGE = 0.015
				BELOW AV = 0.007
		MAINTBTY = 0.247		
			IMPROV H = 0.124	
				OUTSTAND = 0.070
				ABV. AVG = 0.032
				AVERAGE = 0.015
				BELOW AV = 0.007
			RANK = 0.124	
				OUTSTAND = 0.070
				ABV. AVG = 0.032
				AVERAGE = 0.015
				BELOW AV = 0.007
	A/C IMPT = 0.154			
		OUTSTAND = 0.087		
		ABV. AVG = 0.040		
		AVERAGE = 0.018		
		BELOW AV = 0.009		
	INV SIZE = 0.101			
		OUTSTAND = 0.057		
		ABV. AVG = 0.027		
		AVERAGE = 0.012		
		BELOW AV = 0.006		
	A/C YRGP = 0.050			
		OUTSTAND = 0.028		
		ABV. AVG = 0.013		
		AVERAGE = 0.006		
		BELOW AV = 0.003		

```
COST      = 0.200
            LCC      = 0.100
                       OUTSTAND = 0.057
                       ABV. AVG = 0.026
                       AVERAGE  = 0.012
                       BELOW AV = 0.006
            MOD COST = 0.100
                       OUTSTAND = 0.057
                       ABV. AVG = 0.026
                       AVERAGE  = 0.012
                       BELOW AV = 0.006
```

Select the mods with the highest R&M improvement

SYNTHESIS OF LEAF NODES WITH RESPECT TO GOAL

OVERALL INCONSISTENCY INDEX = 0.01

```
OUTSTAND   0.565
ABV. AVG   0.262
AVERAGE    0.118
BELOW AV   0.055
           =====
           1.000
```

ABV. AVG --- Above Average Attributes.
AVERAGE --- Average Attributes.
BELOW AV --- Below Average Attributes.
OUTSTAND --- Outstanding Attributes.

Appendix C: Glossary of Terms Used in ESS Model.

GOAL: Select the mods with the highest R&M improvement.

Glossary of the Terms Used in Model

LCC	---	Life Cycle Costs - Amortized or not?
COST	---	Cost of the Total Projected Modifications.
GOAL	---	Select the mods with the highest R&M improvement
RANK	---	Rank Given in MODAS.
A/C IMPT	---	Impact on the Aircraft Fleet.
A/C YRGP	---	Aircraft Year Group.
ABV. AVG	---	Above Average Attributes.
AVERAGE	---	Average Attributes.
BELOW AV	---	Below Average Attributes.
BENEFITS	---	Benefits Gained By the Modifications.
IMPROV H	---	Improvement Hours.
INV SIZE	---	Inventory Size.
MAINTBTY	---	Maintainability Factors.
MOD COST	---	Total Dollar Amount.
OUTSTAND	---	Outstanding Attributes.
R&M BNFT	---	Reliability and Maintainability Benefits.
RELIABTY	---	Reliability Factors.

Appendix D: Glossary of Acronyms and Abbreviations.

Acronym	Description
A/C	Aircraft
AFLC	Air Force Logistics Command
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
ALC	Air Logistic Center
ANG	Air National Guard
DSS	Decision Support System
ES	Expert System
ESS	Expert Support System
FH	Flying Hour
G063	Data sheet format from AFLC computer system MODAS
HQ	Headquarters
ILS	Integrated Logistic Support
Imp	Improvement
JSG	Joint Studies Group
MIS	Management Information System
MODAS	Maintenance and Operational Data Access System
PC	Personal Computer
POM	Program Objectives Memorandum
P3B	Data from AFLC computer system Pacer Lab
R&M	Reliability and Maintainability
SMO	Special Management Office
SPM	Special Project Manager
TAC	Tactical Air Command
TAF	Tactical Air Forces
USAF	United States Air Force
USAFE	United States Air Forces in Europe

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VITA

Captain Joseph B.B. Nettleton [redacted] in 1972 [redacted] enlisted in the USAF. After graduation from basic training he was assigned to Keesler AFB, Mississippi for electronics training. He served as a ground radio maintenance technician at Randolph AFB, Texas and Zaragoza AB, Spain. Upon return to the United States in 1979, he was again assigned to Randolph AFB, and was cross-trained into computer programming. He worked at HQ/ATC in the logistics plans directorate on a WANG minicomputer. Many after-hours college courses earned him a Bachelors of Applied Arts and Sciences in Occupational Education with emphasis in computer science from Southwest Texas State University in San Marcos, Texas. After his commissioning from Officer Training School in 1983, he was assigned to Chanute AFB, Illinois for the aircraft maintenance officers course. He was then assigned to Luke AFB, Arizona as an aircraft maintenance officer. While at Luke he held positions in the Equipment Maintenance Squadron and the Component Repair Squadron. He attended Squadron Officers School in residence and following graduation was assigned to the 311th Aircraft Maintenance Unit at Luke. He held the assistant OIC position until he was assigned to the Air Force Institute of Technology.

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Thesis Chairman: Curtis R. Cook, Major, USAF
Assistant Professor of Contracting Management

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Block 19 Cont.

Expert support systems (ESS) are systems designed to help decision makers deal with complex, nonprogrammed decisions. This research entailed development, implementation, and validation of an ESS in a "real world" environment. The problem solving technique used here is the analytic hierarchy process, adapted to the microcomputer by Dr. Foreman and others from Decision Support Software in the form of the software package Expert Choice. Included in the research is a background study on decision making in general, the analytic hierarchy process, the evolution of expert support systems, and United States Air Force reliability and maintainability (R&M) issues.

The complex decision chosen for this project was Headquarters Tactical Air Commands's annual prioritization of R&M modifications. These R&M mods, improve the effectiveness of fielded weapon systems. Due to a limited budget, not all modifications can be funded in a given year. Therefore, TAC must prioritize the modifications, trading off benefits offered with the cost of the proposed change. This research includes a model designed by the author using Expert Choice to prioritize these modifications that offer the greatest benefit/cost return. The model improves responsiveness to changes, increases flexibility, and improves the reliability of the decision-making process.